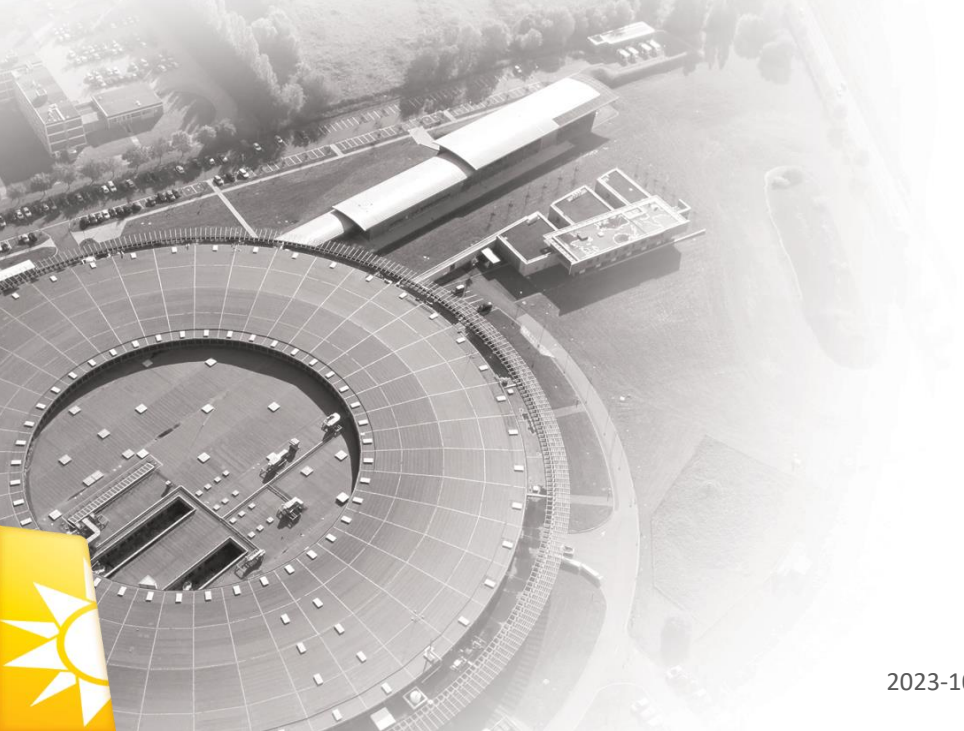
Overcoming Challenges in 2D-Nanopositioning Systems

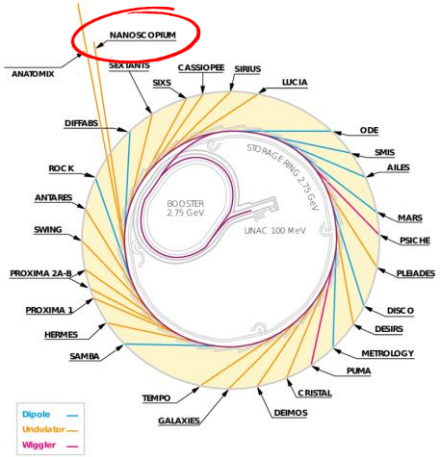
MOCRAF 2023: Overcoming Existing System Limits



Laura MUNOZ on behalf of Christer ENGBLOM

Introduction & Setup

Introduction



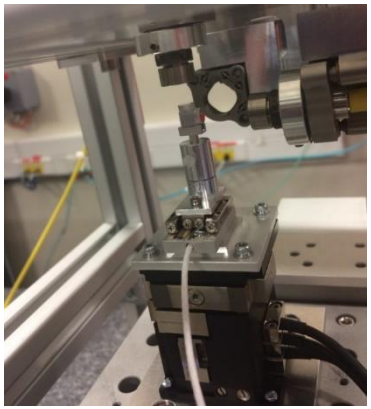
The Nanoscopium beamline (SOLEIL)

Offer 2D-nano-imaging services :

- Sample Sizes: < 100x100 µm
- Continuous scans (aka Flyscan)
- **Imaging resolutions: 50 nm**

2D-nano-Scanner Problems

- Degrading/unreliable positioning/movement performance
  - Short term (< 30 min) → Long term (Several Hours)
- Strange limit switch activation (usually after some use)



Imaging resolutions (today): ~150 nm

Control Architecture

Gallil Controller

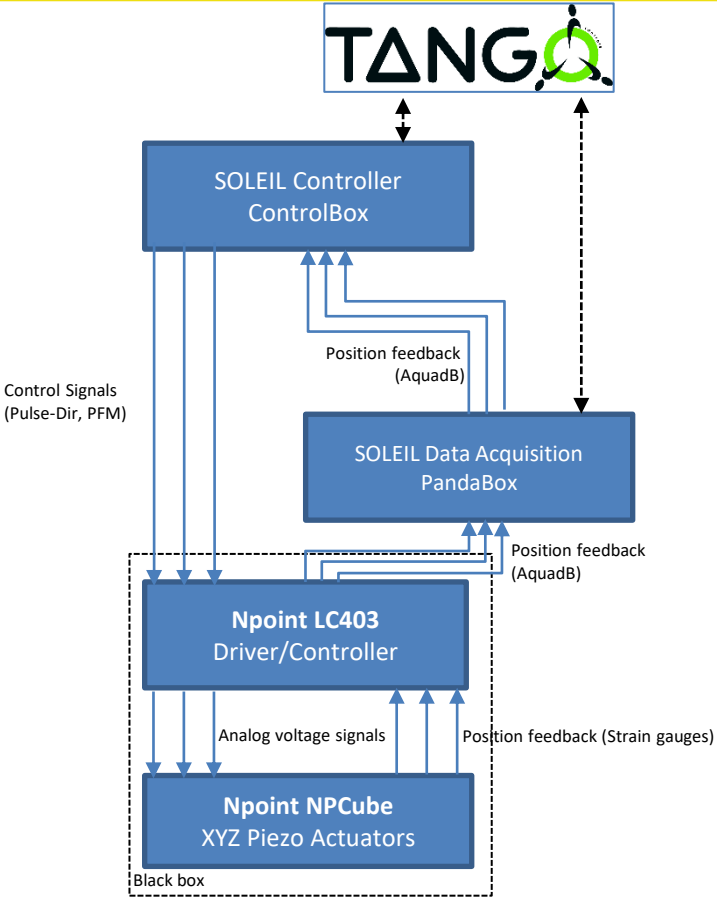
- ControlBox (Point-to-Point, open-loop)

Driver/Controller

- Npoint LC-403 (Closed-loop with PID)
  - Pulse-Dir (PFM)
  - AquadB interface

Actuators & Sensors

- Npoint NPCube
  - Piezo, stacked design (100x100x100 µm range)
  - Strain gauges sensors for positioning

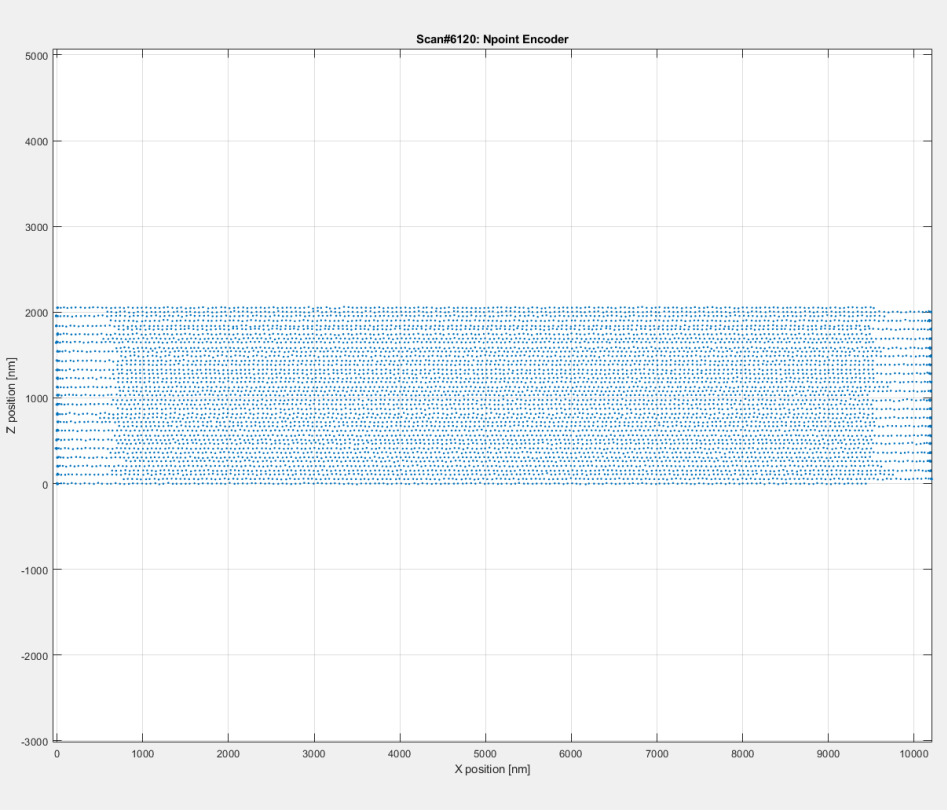


Setup

Scan Trajectory Type

« Fast » 2D-raster scans

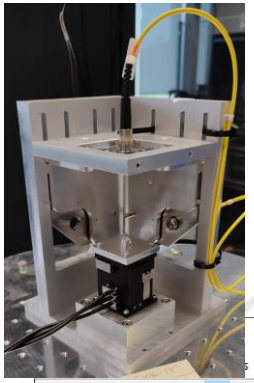
- Continuos scans on **X-axis** (Flyscan)
  (deca-µm range with deca-µm speeds)
- Step-scans on **Z-axis**
  (deca-µm range with deca-nanometric steps)
- While holding position on **Y-axis**



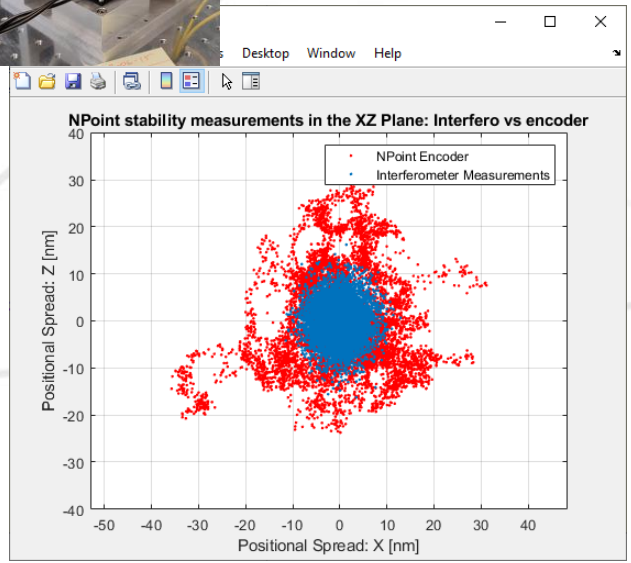
Example (2D- raster flyscan)

Actions

- External Metrology Frame
  - Interferometers (Attocube)
  - Rigid Aluminium
  - Mechanical adjustments (Piezo stage, interferometer sensors, mirrors, etc)



- Several interventions (in beamline):
  - PID retuning (Npoint LC-403)
  - Sensor recalibrations (Npoint LC-403)
  - Positioning tests
    - Positioning (step-responses)
    - 2D-flyscans
  - Stability tests (interferometer vs encoder)
    - During/after system startup (ex: heating effects)
    - During/after 2D-scans



Actions

- External Metrology Frame
  - Interferometers (Attocube
  - Rigid Aluminium

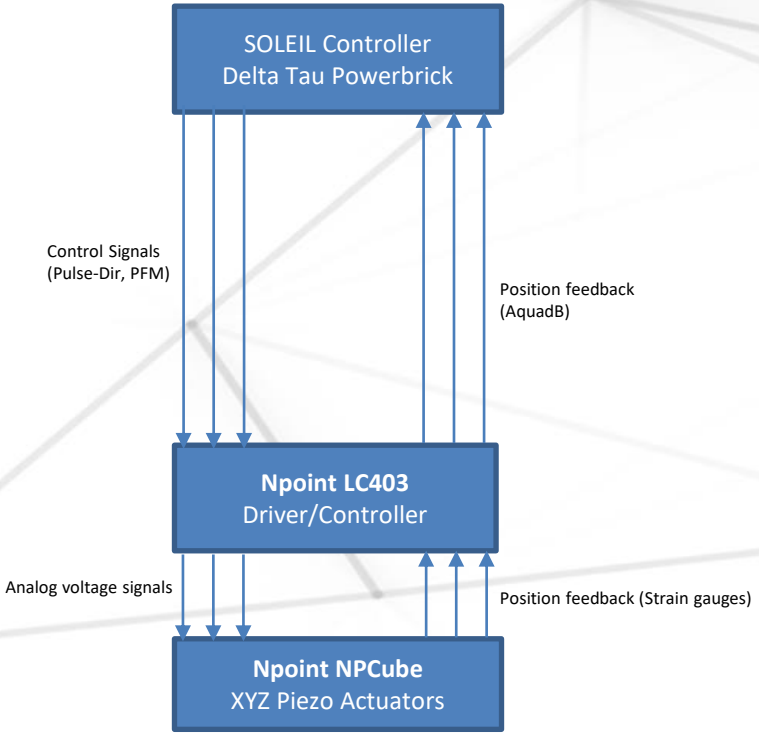
- Several interventions on be
(Usually half-day → full-day
  - PID tuning (Npoint LC-40
  - Mechanical adjustments (
sensors, mirrors, etc)
  - Sensor recalibrations (Np
  - Positioning tests
    - Positioning (step-respon
    - 2D-flyscans
  - Stability tests (interferome
    - During/after system star
    - During/after 2D-scans

Have yielded **mixed results**. And when positive, usually only temporary or just over very short term scans.

In-Lab Tests

In-Lab Tests

- System (Npoint) was installed in the Electronics laboratory for **long-term testing**.
  - With Metrology frame + interferometers
  - Without PandaBox
- Temperature sensor installed on metrology frame
- SOLEIL ControlBox was eventually replaced with high-performing Delta Tau/Omron Powerbrick Controller
- Executed **many automated, long-term (24h), and large (~< 90x90 µm) XZ- scans** in various configurations
- All scans are monitored using interferometers on the XZ-axes

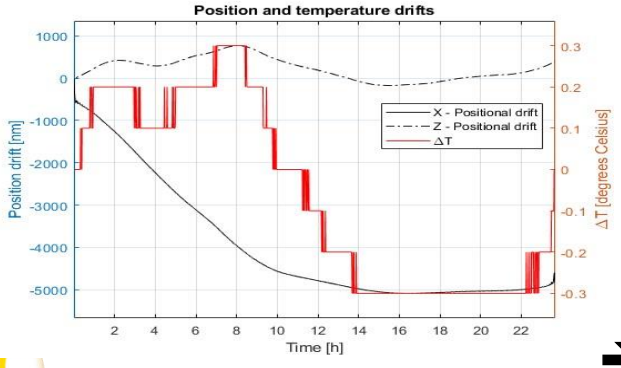


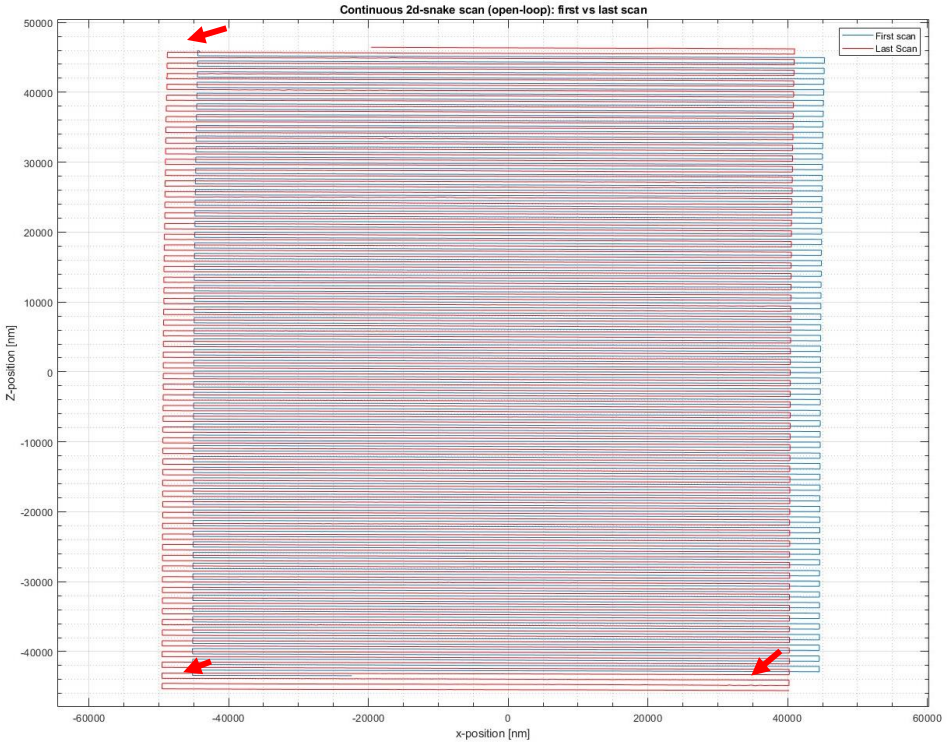
In-Lab Tests

Open-loop Tests
(back-to-back scans during ~23 h)

- **First scan** vs **Last scan**
  - 2D-scan has **"shifted"** several µm + **activated negative limit** switches for X and Z.

X- axis « drifted » 5 µm during 14h of constant use!





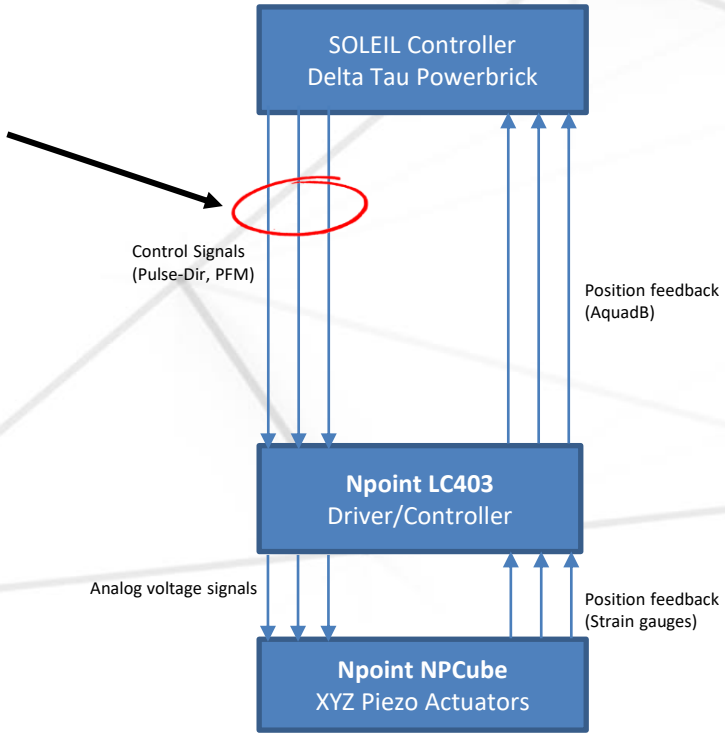
➔ **Errors of up to ~350 nm/h**

In-Lab Tests

« Slow drift » problem stems from control pulses lost over time. Only a few pulses lost every 1 million pulses ➔ **Enough to drift several µm over hours of constant use.**

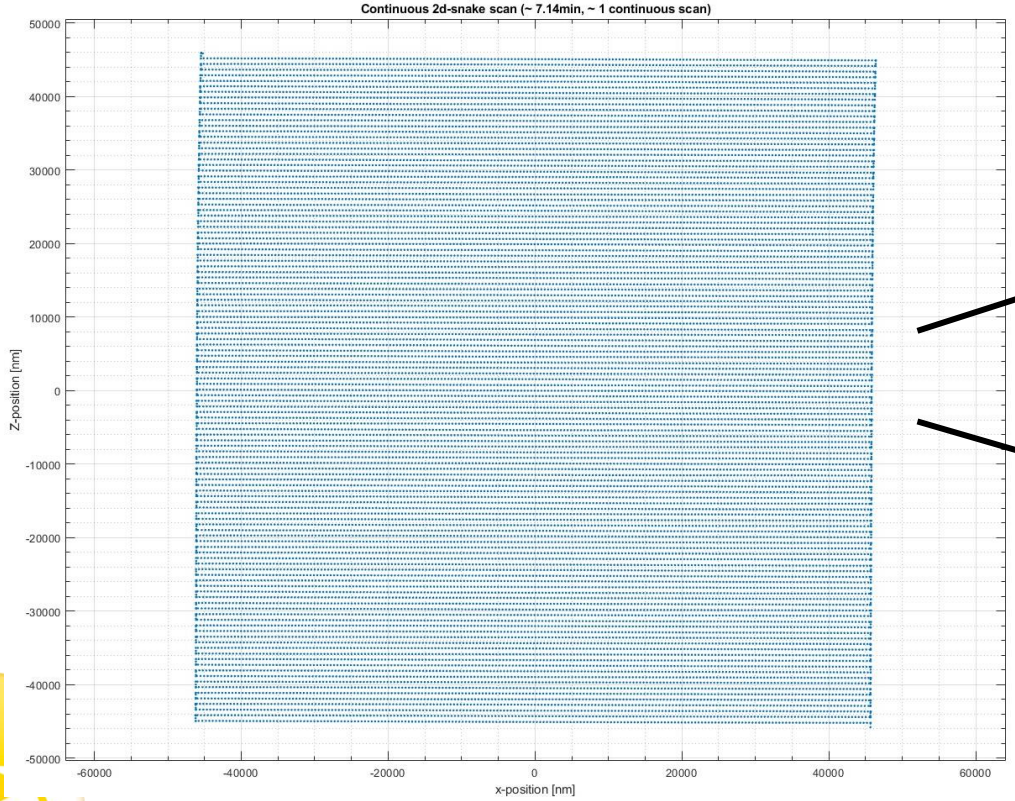
Solution:

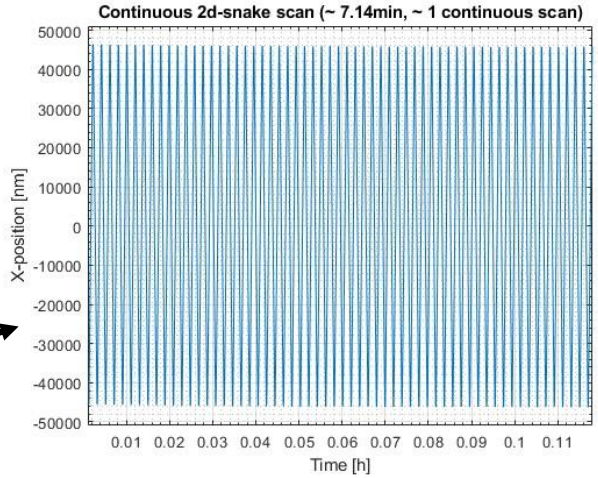
Close the loop (PID) at the Powerbrick-controller level (provided that the encoder is fully functional).

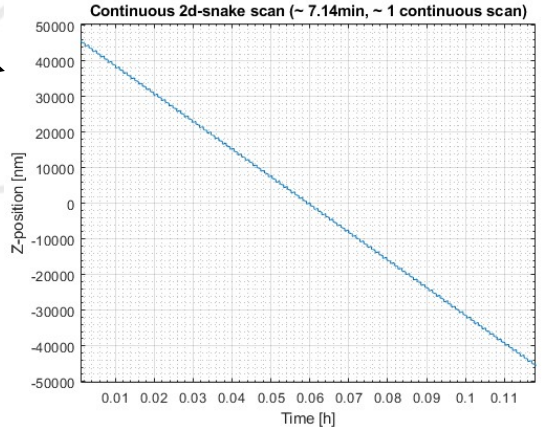


Closed-loop Tests
(one 2D-scan, ~7.14min)

In-Lab Tests

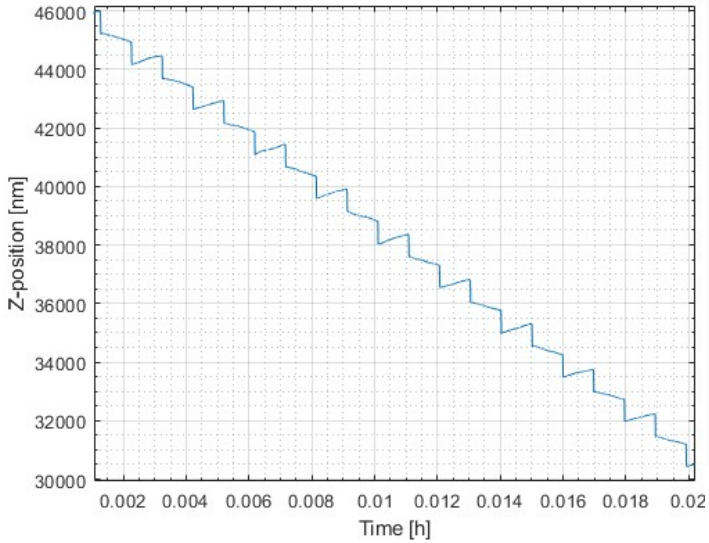


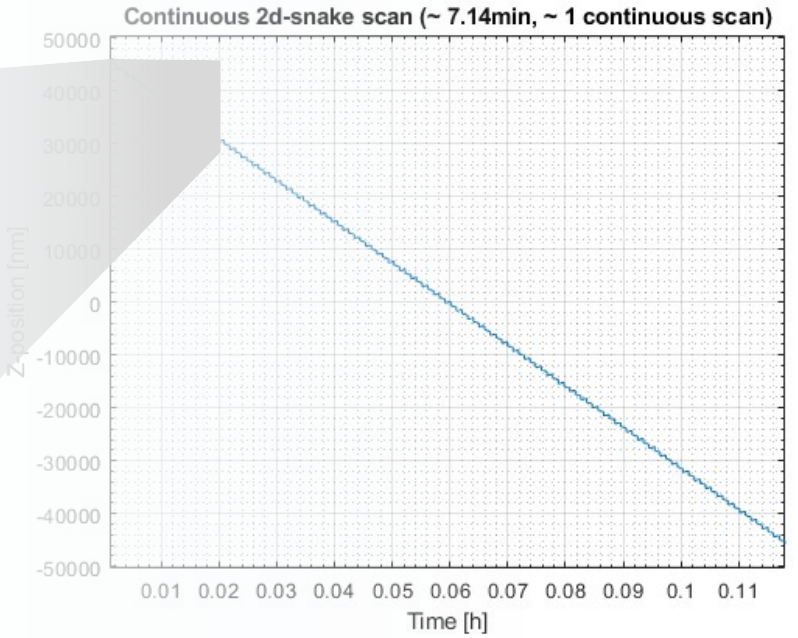




Closed-loop Tests
(one 2D-scan, ~7.14min)

In-Lab Tests





Z- movements are supposed to hold a « staircase » -shape.

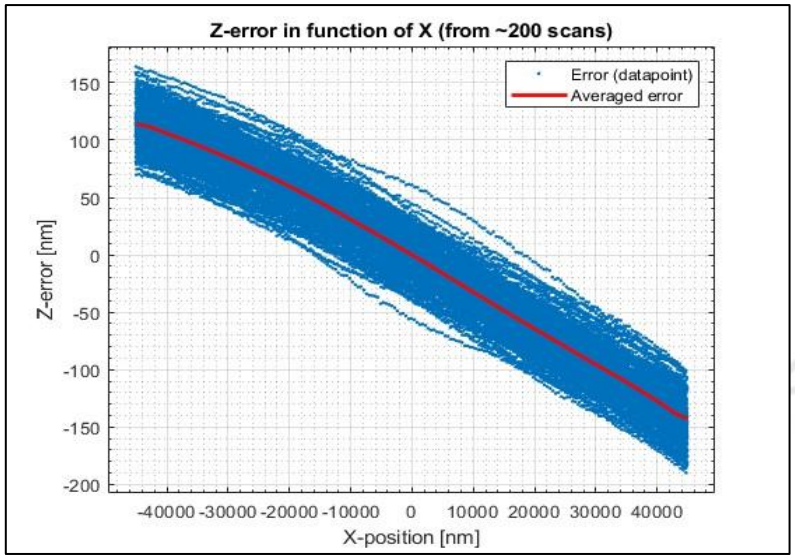
→ There are motion errors/crosstalk between axes X and Z.

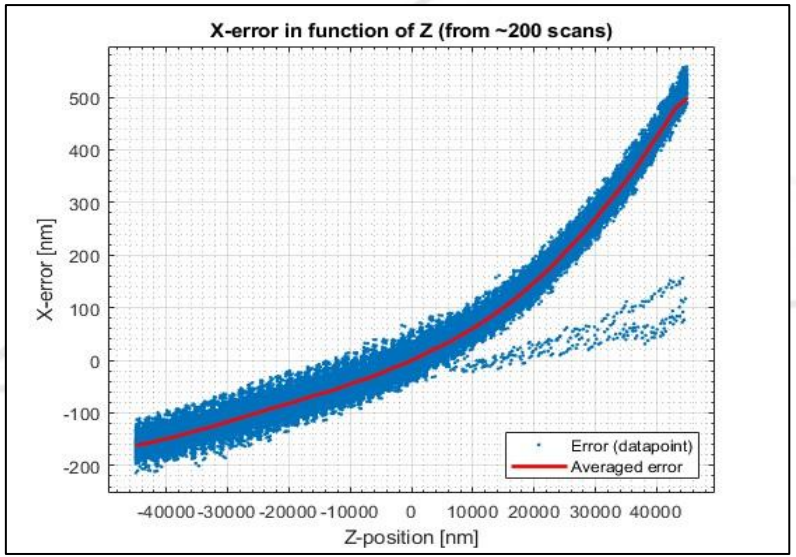
In-Lab Tests

Solution:

Calculate **repeteable crosstalk error** from long-term data and **apply active cross-axis compensation** in the Powerbrick Controller.

➔ **errors of up to ~500 nm**





Closed-loop Tests
(Long-term 2D-scans, ~23h)

Key Actions

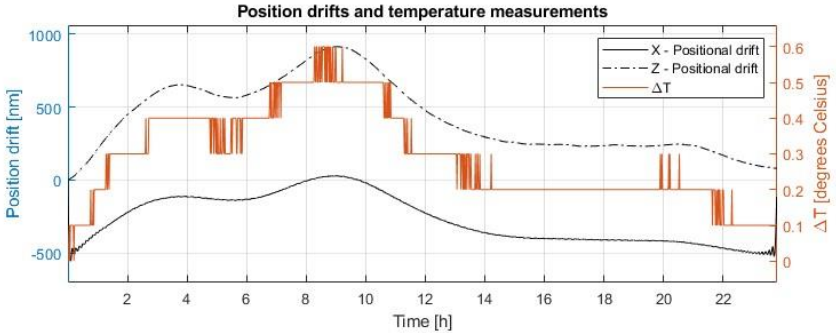
Positional XZ- drifts larger than 750 nm evident (the Z-lines «blur»).

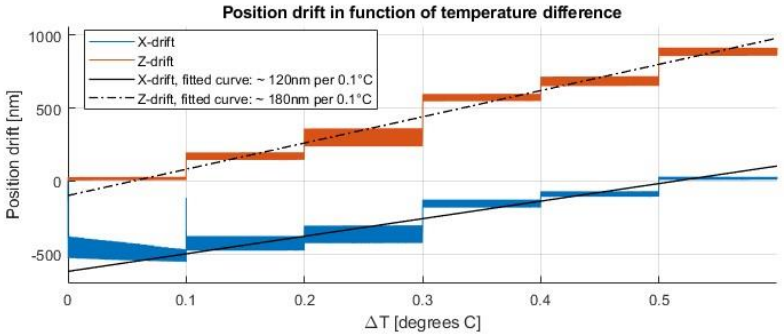
Temperature seems to have a high linear correlation.

Measurement errors of up to ~180 nm/0.1°C

Possible source of positional drifts measurements:

Thermal dilations of the metrology frame





In-Lab Tests

What did we learn?

- The SOLEIL Controller (Delta Tau) needs to be in closed-loop
  (eliminate position drift errors of up to ~350 nm/h or more)

- We need to actively correct for XZ-crosstalk errors.
  (eliminate repeatable errors of up to ~500 nm)

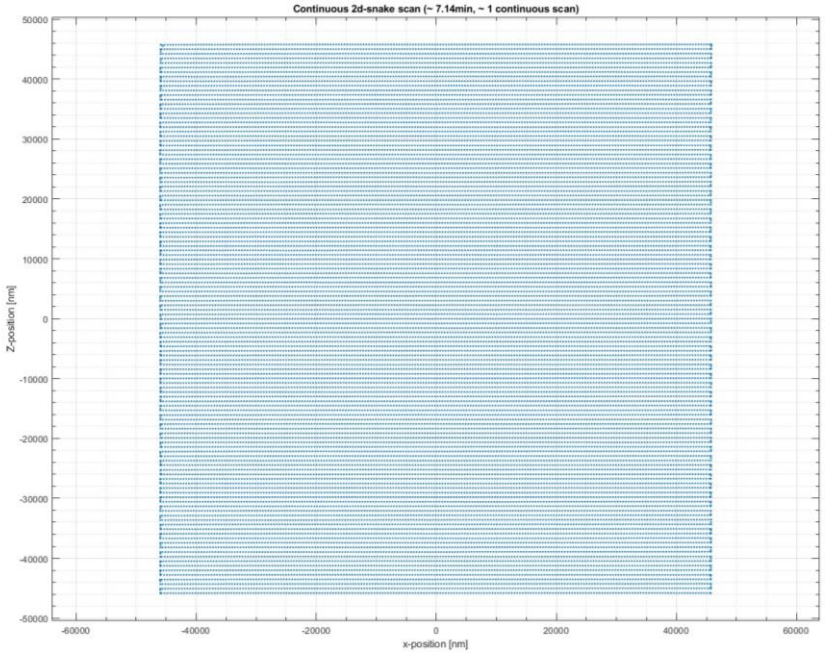
- Temperature differences has non-negligible impact on our metrology frame, causing measurements errors
  (Measurement errors of up to ~180 nm/0.1°C)

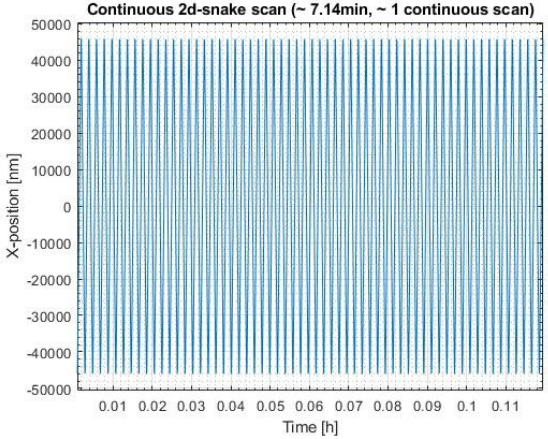
Beamline Tests

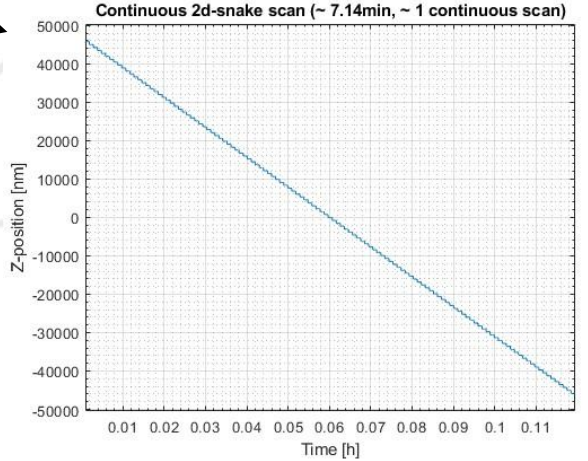
(With Metrology Frame, not beam)

Closed-loop Tests
(One 2D-scan, ~7.14min)

Beamline Tests



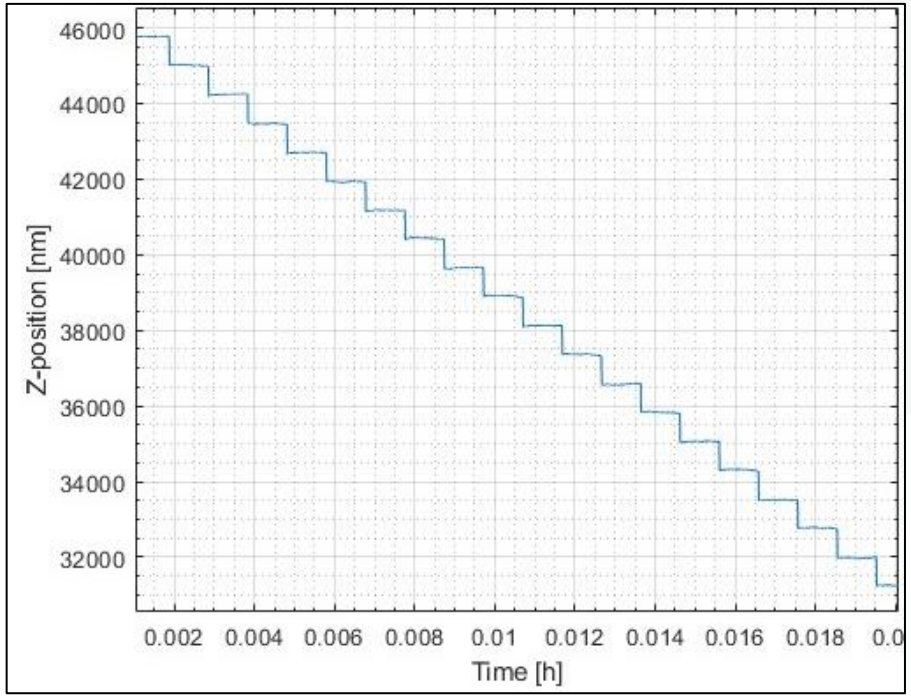


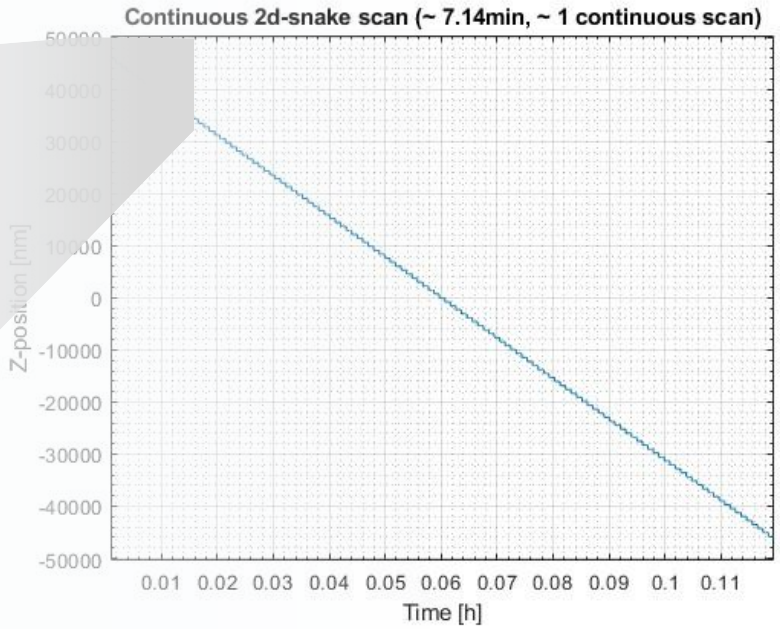


Closed-loop Tests
(One 2D-scan, ~7.14min)

Beamline Tests

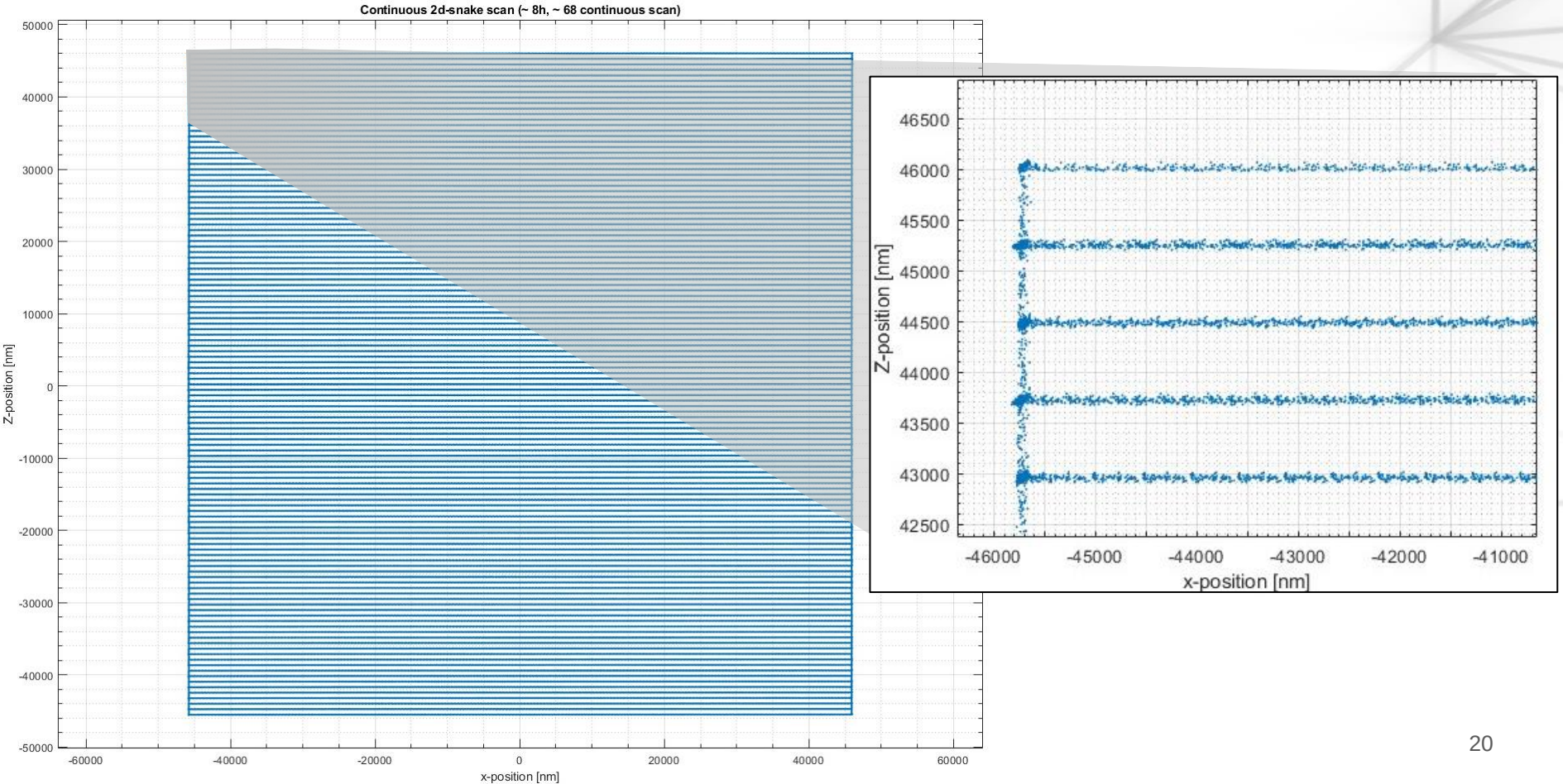
Z- movements are exhibiting a nice « staircase » -shape.





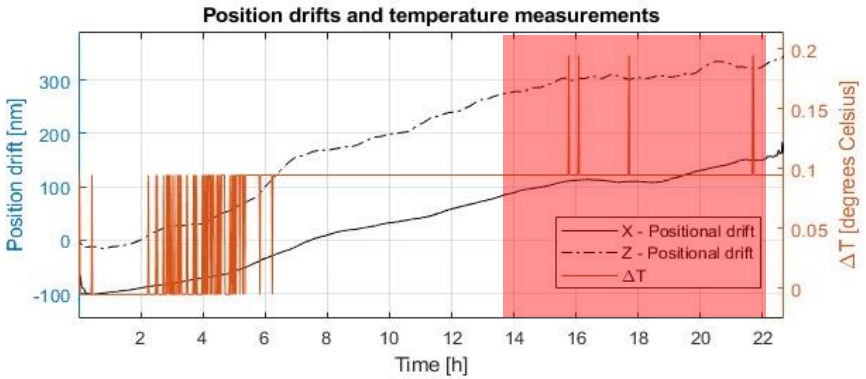
Closed-loop Tests
(Long-term 2D-scans, ~8h)

Beamline Tests



« Spread » around Z during the 8h scan: ~< 100 nm

However (during this 8h period, marked red), there are temperature fluctuations (+/- 0.1°C), indicating possible measurement errors from metrology frame.



Actual results may be better (temperature sensor + metrology frame limitation).

Need to test with beam to verify !!!